Nonintrusive Measurement of Fluid Flows in High-Pressure, High-Speed Cryogenic Regimes

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The purpose of this work is to measure volumetric flow rate of cryofluids under single-phase and some two-phase conditions. The cryofluids flow inside a thin-walled conduit at velocities that can exceed 35 m/sec (115 ft/sec). Flow is measured ultrasonically by using external ultrasonic transducers that clamp onto the outside of the conduit. This type of noninvasive flow measurement is desirable in many applications in general and specifically in applications such as the lox and LH_2 ducts of the Space Shuttle Main Engine (SSME).

The small clamp-on ultrasonic transducer (fig. 99) developed under Contract NAS8-38429 was measured in the contrapropagation mode, single-phase LN_2 flowing inside space shuttle ducts having diameters either near 33 mm (1.30 in) or near 100 mm (3.93 in) and wall thickness near 3 mm (0.12 in). Flow velocity ranged between ~0.1 (3 ft/sec) and 6 m/sec (19.7 ft/sec). In another test (conducted in July 1996 at the BETASSO water treatment plant in Boulder, CO.) the transducers operated in the contrapropagation mode in conjunction with a commercial portable ultrasonic flowmeter (Panametrics' Model PT868). Dr. Jim Siegwarth of NIST/Boulder was a collaborator in this test (fig. 100) in which water was flowing (up to 37 m/sec (121 ft/sec)) in the low-pressure oxygen turbopump (LPOT) turbine drive duct (58.42 mm (2.3 in) ID×4.19 mm (0.165 in) wall).

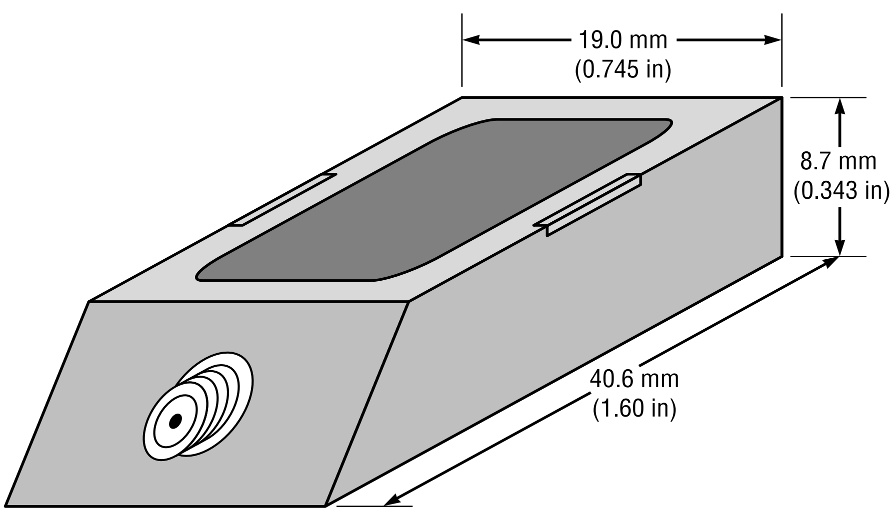

FIGURE 99.—Small mass clamp-on transducer, mass=29 grams, frequency 500 kHz.

The long-term objective of the program is to measure lox and LH_2 flowing inside the ducts of the SSME. The preliminary piggyback testing was done with lox flowing in SSME's high-pressure oxygen turbopump (HPOTP) discharge duct (111 mm (4.37 in) ID×4.45 mm (0.175 in) wall) and in the fuel pre-burner (FPB) supply (50.7 mm (1.996 in) ID×3.23 mm (0.127 in) wall) at the MSFC test stand. The transducers and their couplant survived the duct vibration and the cryogenic temperature of the lox. The available commercial flowmeter systems, however, have not yet successfully measured flow in the contrapropagation mode in these tests.

Our plans are to conduct more tests to better understand the "violent" conditions (flow turbulence and duct vibration) of the SSME ducts. Tests will be performed with the transducers operating in the contra-propagation and reflection modes in conjunction with Panametrics' commercial flowmeter. Tests will first be conducted in laboratory water or LN_2 flow loop. Later tests will be conducted on the lox duct of the SSME at the Stennis Space Center test stand. It appears that the high-velocity, highly turbulent, cryo conditions may require signal processing methods that are more robust than those that were commercially available during the year covered by this reported. Such improved methods are already under development for high-flow highly turbulent fluids, especially gases, and should be ready for testing in the coming year on single- and two-phase cryofluids.

Lynnworth, L.C.; Matson, J.E.; Nguyen, T.H.; Powers, W.T.: "Small-Inertia Clamp-on Cryogenic Flowmeter Transducer." *1992 Conference on Advanced Earth-to-Orbit Propulsion Technology*, vol. I, pp. 207–216, May 19–21, 1992.

Lynnworth, L.C.; Nguyen, T.H.; Liu, Y.; and Stein, P.: "Clamp-on Flow Velocity and Density Transducers for Liquid Nitrogen and Other Cryogenic Applications, Especially in Thin-Walled Conduits." *1994 Conference on Advanced Earth-to-Orbit Propulsion Technology*, vol. I, pp. 97–104, September 1994.

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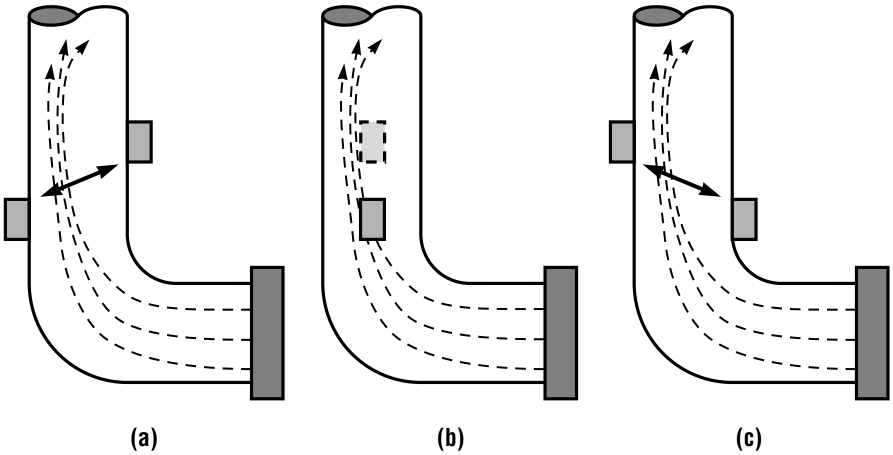

FIGURE 100.—Test with water flowing (up to 37 m/s) inside the LPOT turbine drive duct. In (a) the flow velocity, measured along the path represented by the double-arrowed line, was lower than in (c). However, the average of the flow velocities in (a) and (c) was approximately equal to the flow velocity in (b). A practical observation can be drawn from the test. To avoid the influence of swirl due to the upstream elbow: (1) a one-path flowmeter system should have a pair of transducers mounted in a plane such that it is perpendicular to the plane of the elbow as in (b); or (2) a two-path flowmeter system should have two pairs of transducers mounted in the same plane as the plane of the elbow as in (a) and (c) combined. Note: The flow lines are hypothetical.

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